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(54) Using a coated fuel injector and method of making

(57) A method of using an amorphous carbon-based coating to extend the operating life of a fuel injector having a needle operating within a valve body, the valve body, the valve and body having steel surfaces subject to repeated impact and sliding friction contact over the operating life of the injector. The method comprises (a) providing the steel surfaces of at least one of the needle and body with an ion implanted stabilised amorphous carbon-based coating in a thickness of 1-10 micrometers, the coating having low internal stresses and low coefficient of friction independent of humidity and being stabilised by the presence of up to 30% by weight of carbide forming material selected from the group of silicon, titanium and tungsten, and (b) repeatedly and rapidly actuating the fuel injector in time periods of .5-1.5 micro-seconds for a single acutations thereby subjecting the valve coated surfaces to substantially continuous sliding contact and needle impact forces of 70,000-200,000 psi, the actuation being carried out in the absence of lubricious fuel at the coated surfaces whereby wear is significantly reduced by atomic transfer of coating atoms to mating surfaces during impact or sliding contact. Also disclosed is a method of making a fuel injector with an extended life needle having impact and sliding friction contact surfaces not all of which are exposed when viewed from a single direction.

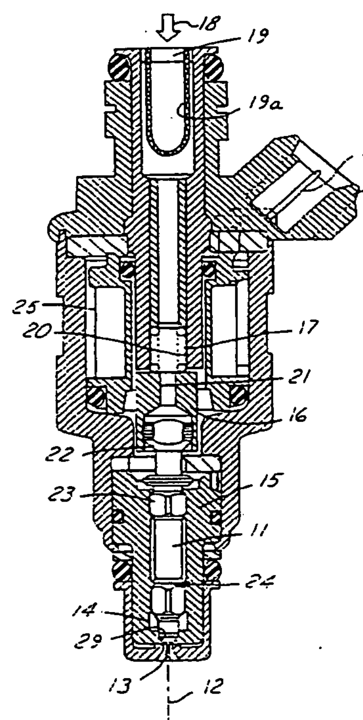

FIG.1

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Pressurised fuel 18 is placed in normal communication with the fuel cup 14 by passing from an inlet 19 through a screen 19a, through a spring chamber 20, through opening 21 of element 16 and thence through openings 22 to the exterior of element 16, and finally around the pentagonal sides 23 of the needle lands 24. To open the aperture, a solenoid coil 25 is energised to force element 16 against the spring 17 and move the pintle 26 to an open position with respect to aperture 13. Suitable wiring 27 connects to the coil by way of a connector terminal 28. The pintle is cyclically opened and closed within a time period of .5-1.5 milliseconds, and the inertia of such rapid movement results in high impact stresses at the valve body seat 29 resulting from needle tip contact.

As shown in Figure 2, the needle 11 is formed of a hardened and corrosive resistant steel alloy, such as 440 stainless steel; it has contact surfaces 30 (corners of pentagonal shaped lands 24) which slide in contact with the interior cylindrical surface 31 of the valve body 15. The needle 11 also has an annular tip surface 32 (which may be conical) formed on the tip of the pintle 33 of the needle which contacts the interior seat surface 29 of the valve body 15 with an impact force (when urged by spring 17 to close the aperture 13 along the axis of such seat 29). When coil 25 is energised, the electromagnetic force operates on the armature element 16 to pull the needle 11 away from the seat 29 a distance of 10-260 micrometers, depending on the injector type.

Such contact surfaces 30 and 32 can experience excessive wear (galling, abrasion, surface fatigue) in the absence of a liquid lubricant such as will be experienced with flexibly fuelled engines utilising propane gas, natural gas, gasoline or diesel fuel with a low sulphur content. This will occur in spite of the valve body being usually comprised of 440 stainless steel. The sliding contact surfaces 30 without the coating of this invention, may first experience galling when the injector is used over a reasonable period of time. Such galling may cause surfaces 30 to cease up against surface 31 of the valve body, causing the injectors to stop functioning. Frictional wear may be rapid enough for such uncoated surfaces to prevent ceasing and eventually cause the normal diametrical clearance between surfaces 30 and interior surface 31 (2-5 microns) to increase to about 15 microns over a period of use that is roughly equivalent to 10,000-13,000 vehicular miles or 13 million cycles of the injector.

Since the injector needle is typically actuated to have a cycle time period of .5-1.5 milliseconds and such cycles are continuously repeated, high impact stresses will be created in seat surface 29 as a result of aperture closing contact therebetween. Such impact stresses can be in the range of 60,000-200,000 psi. The initial contact area of conical surface 32 with conical seat 34 is never perfect and results in localised areas that upon initial contact can cause the stress to rise to the yield point of the body or needle material (i.e. about 200,000 psi for steel). However, during constructive break-in use, the metal at such localised contact areas will deform to bring down the stress level to about 70,000 psi and stay at such levels with little or no frictional wear. Without the coating of this invention at such stressed areas, the surfaces would suffer from material fatigue and deformation that may allow excessive fuel to be injected through the aperture 13. The dynamic flow rate of the fuel can deviate off target by as much as 20%.

Surfaces of at least one of the needle or the valve body is provided with an ion implanted stabilised amorphous carbon-based coating having low internal stresses and low friction when subjected to a humid condition and is stabilised by the presence of up to 30% by weight of a carbide forming material selected from the group of silicon, titanium, and tungsten. As shown in Figure 3, the surfaces 30 and 32 of only the needle valve pintle are preferably coated to a thickness of 1-10 micrometers. A capacitively coupled parallel plate RF driven plasma reactor 40 may be used to effect both etching cleaning as well as coating of such surfaces. The reactor is advantageously used with a low pressure plasma enhanced chemical vapour deposition technique.

The needle 11 is desirably degreased prior to being subjected to the etching and coating technique in the RF driven plasma reactor. Such degreasing may be carried out by the use of soap, (KOH) and water acetone rinse, nitric acid etch and alcohol. The needle 11 is positioned with one end 11a of the needle on an RF powered fixture, such as cathodic electrode pedestal 41 of the RF apparatus, and the opposite end 11b of the needle valve is exposed to allow the plasma to envelope it and is preferably positioned to point generally toward the anoidic electrode 43. Any surfaces of the needle valve (i.e. surface 42) that are not to be coated or treated are usually masked by use of a membrane 44 as shown in Figure 3.

After the chamber 45 has been evacuated to a system based pressure of about 4.0x 10^{-6} torr or less, an inert gas, such as argon, may be admitted to the chamber through gas inlet 46, while RF power from source 47 is directed to the substrate cathode electrode 41. This generates a negative bias voltage of 100-500 volts relative to the plasma which draws ions from the plasma and accelerates them to the needle valve pintle which is in conductive contact with the cathode electrode. Chemically inert argon ions dislodge other atoms of the steel pintle, thereby further cleaning all of the surfaces of the valve pintle by etching, including surfaces 30 and 32.

Deposition of the coating is then commenced by introducing a carbon coating precursor gas 49 in the form methane, acetylene, propane, butane, pentane or pentene, as the flow of inert gas is stopped, through inlet 46. At the same time a coating stabilising material is also ion deposited along with the carbon ions. Side electrodes 50, 51 may be used to control the degree of negative potential as well as the field of the plasma 48. The

generally to an opposite polarity electrode of said apparatus, being exposed for the plasma, created with the other electrode, to envelope such needle, any surface of said needle that is not to be surface treated being masked;
(b) cleaning and etching at least the impact and sliding contact surfaces of said needle;
(c) while providing ionising material to the electromagnetic field generated between the electrodes, carrying out said plasma enhanced vapour deposition to deposit an amorphous carbon coating in a thickness of 1-10 micrometers, said carbon coating being stabilised by the presence of up to 30% by weight of a carbide former with said steel, said carbide former being selected from the group of silicon, titanium and tungsten.

7. A method as claimed in claim 6, in which step (c) is carried out so that the ions are directed by the electric field to wrap around said needle to coat all surfaces even though blind to one of the electrodes.

8. A method as claimed in claim 6 or 7, in which the starting material for the ion stream, for depositing the amorphous carbon based coating, selected from the group of methane acetylene, propane, butane, pentane and pentelene.

9. A method as claimed in claim 6, 7 or 8, the carbide former material stabilising the amorphous coating is comprised of a tetramethyl silane or diethyl silane gas introduced along with the hydrocarbon gases of the starting material.

10. A method as claimed in any one of claims 6 to 9, in which titanium or tungsten is selected as the carbide-former, and solid titanium or tungsten is placed on a magnetic cathode and a voltage is applied to strip and sputter ions of said titanium or tungsten into said plasma for impregnating the amorphous carbon coating with said stabilising material.

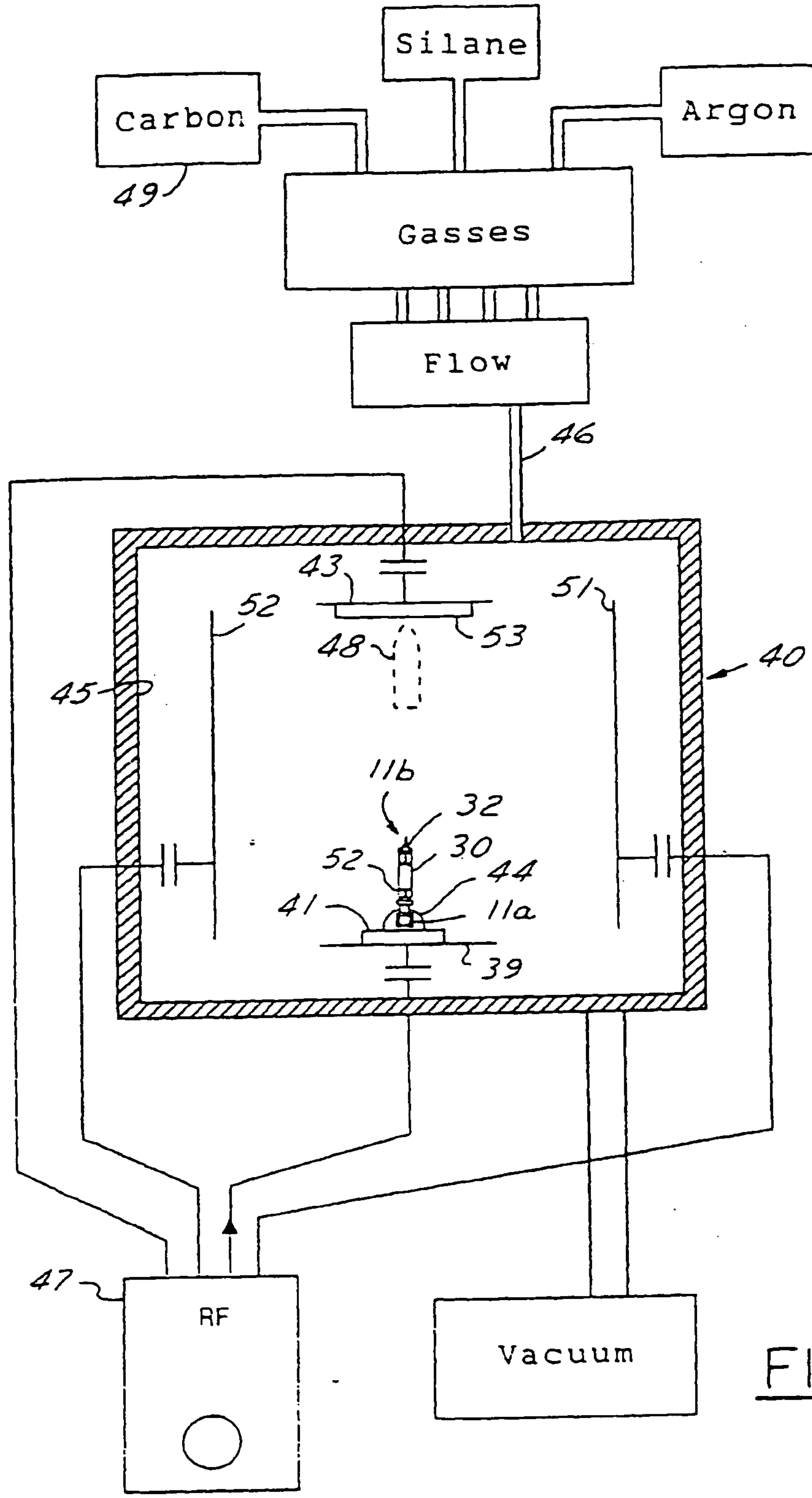
Silane
Carbon
Argon
49
Gasses
Flow
46
43
52
51
53
48
40
45
11b
32
52
30
44
41
11a
39
47
RF
Vacuum

FIG.3

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EUROPEAN SEARCH REPORT

Application Number
EP 97 30 5027

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
D,A	US 5 409 165 A (CARROLL III JOHN T ET AL) 25 April 1995 * abstract *	1	F02M61/16 F02M51/08 C23C16/26
A	US 4 951 878 A (CASEY GARY L ET AL) 28 August 1990 * column 6, line 7 - line 27; figure 2 *	1	
A	EP 0 651 069 A (VLAAMSE INSTELLING VOOR TECHNO) 3 May 1995 * page 2, line 1 - page 3, line 22 *	1,6	

TECHNICAL FIELDS SEARCHED (Int.Cl.6)

F02M
C23C

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	6 October 1997	Torle, E

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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